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FUZZY LOGIC BASED POWER SYSTEM STABILIZER WITH SYNTHESIZED ACCELERATING POWER AS INPUT SIGNAL

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ABSTRACT

Small signal oscillations can be effectively damped using power system stabilizers. In this paper Fuzzy Logic Power System Stabilizer (FLPSS) is designed to damp low frequency oscillations and improve the stability of the power system. Speed deviation and accelerating power are taken as inputs to the FLPSS. The rules are framed using if - then format. Mat Lab and Simulink are used for analysis purpose. The effectiveness of proposed FLPSS is demonstrated by considering Single Machine connected to Infinite Bus system (SMIB). A comparative study of results obtained from FLPSS and CPSS with regard to damping of oscillations is made.

KEYWORDS: Stability, Low Frequency Oscillations, Fuzzy Logic Power System Stabilizer, Supplementary Modulation Controller

INTRODUCTION

The power system is becoming more and more complex as the demand for power is increasing. The problem of small signal oscillation is very vital in a complex power system. The synchronism of power system will be lost if the oscillations are not damped. Therefore for secure operation of power systems adequate measures are required to be initiated to damp these oscillations. Power system stabilizer (PSS) is the most widely used supplementary modulation controller in the generator excitation system to damp low frequency oscillations. The objective of PSS is to provide additional damping torque to the generator rotor in phase with speed deviation. The design of conventional PSS is based on linear zed mathematical model. The parameters of conventional PSS are determined at nominal operating point. When the operating point changes the performance of PSS may deteriorate. Hence the researchers opted for more intelligent control such as fuzzy PSS, ANN based PSS etc[1]. The stability of a power system can be enhanced by employing fuzzy logic power system stabilizer [2]. Speed deviation and acceleration can be considered as inputs to the fuzzy controller. Synchronous machine can be modeled based on Heffron-Phillip model[3,4]. For small signal stability analysis Heffron-Phillip model gives acceptable results. Depending on number of linguistic variables the rules required to build FLPSS varies. With two input linguistic variables only four rules can be employed to model FLPSS [5]. PSS is effective in damping low frequency oscillations. Further, it can also improve the system stability. This paper describes a Fuzzy logic based PSS to damp low frequency oscillations in a power system and improve system stability. Normally speed deviation and acceleration are considered as inputs to the controller. In this paper speed deviation and synthesized accelerating power are considered as inputs to the controller. The synthesized accelerating power signal has the advantage of eliminating the problem of torsional interactions and improved reliability [6]. The performance of the PSS is evaluated by simulating small disturbance and a three phase fault at the generator terminal separately.

Fuzzy Logic

Lotfi Zadeh introduced a mathematical tool to deal with uncertainty in data called fuzzy logic tool. Fuzzy theory provides a systematic procedure to represent linguistic variables such as ‘low’, ‘high’, ‘medium’. The fuzzy logic theory is not a crisp logic; it is based on membership function. It helps us in dealing with uncertainty or ambiguous data. Set membership idea is used in decision making under uncertainty condition. The membership can take a value between ‘0’ and ‘1’. Different types of membership functions like trapezoidal, triangular, sigmoid, Gaussian etc. can be used for analysis. Based on the requirement and constraint the membership value is decided.

Fuzzy set is represented as

A={(x, a(x))}, x ε X, a(x) = Degree (x ε A)

where xεX: possibility distribution and a(x): membership function.

GENERATOR MODELLING

The Figure 1 shows the single line diagram of a SMIB system.

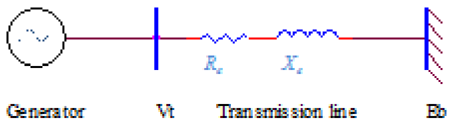

Figure 1: Single Machine Connected to Infinite Bus

Synchronous machine model 1.0 is employed for analysis[6].

The machine equations are:

$$\frac{d\delta}{dt} = \omega_B (S_m - S_{mo}) \tag{1}$$

$$\frac{dS_m}{dt} = \frac{1}{2H}\left[-D(S_m - S_{mo}) + T_m - T_e\right] \tag{2}$$

$$\frac{dE_q^{'}}{dt} = \frac{1}{T_{do}^{'}}\left[-E_q^{'} + (x_d - x_d^{'})i_d + E_{fd}\right] \tag{3}$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_a}\left[(V_{ref} - V + V_{pss})K_a + E_{fd}\right] \tag{4}$$

$$T_e = E_q^{'} i_q - (x_q - x_d^{'}) i_d i_q \tag{5}$$

$$(V_q + jV_d) = (Z_r + jZ_i)(i_q + ji_d) + (h_1 + jh_2)E_b e^{-j\delta} \tag{6}$$

$$F_1 = (h_1 E_b \cos\delta + h_2 E_b \sin\delta - E_q^{'}) \tag{7}$$

$$F_2 = (h_2 E_b \cos\delta - h_1 E_b \sin\delta) \tag{8}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \left[Z^{-1} \right] \begin{bmatrix} F_1 \\ F_2 \end{bmatrix} \tag{9}$$

The synchronous machine is modelled using MATLAB and simulink blocks.

POWER SYSTEM STABILIZER

Power system stabilizers are commonly employed to damp low frequency oscillations. PSS produces additional damping torque to the rotor in phase with speed deviation. Figure 2 shows a typical conventional PSS. Conventional PSS has washout circuit and dynamic compensator. The washout circuit acts as high pass filter. T_w is the wash out time constant, K_s is the PSS gain, T_1 and T_2 are the time constant of the compensator. Speed deviation is fed as input to the compensator and stabilizer output is the modulating signal in the excitation system. The parameters of CPSS [6] are T_w: 2 secs, T_1: 0.078 secs, T_2: 0.027 secs and K_s: 16.

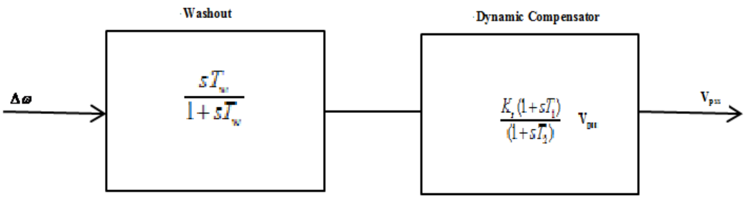

Figure 2: Conventional PSS

FUZYY LOGIC POWER SYSTEM STABILIZER

Fuzzy Logic Controller

Fuzzy controllers are used to build the FLPSS. Figure 3 shows the structure of Fuzzy logic controller (FLC). FLC has four components.

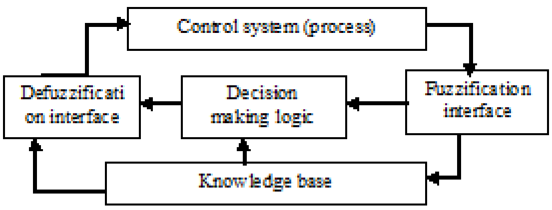

Figure 3: Structure of Fuzzy Logic Controller

- **Fuzzifiction:** The input variables are measured (e.g. speed, acceleration) and converted to suitable linguistic variables with suitable membership function. The linguistic variables used are; NB(Negative Big), NM (Negative Medium), NS(Negative Small), Z (Zero), PS (Positive Small), PM(Positive Medium) and PB (Positive Big).

- **Knowledge Base:** The knowledge base has a rule base where fuzzy data manipulation takes place on set of defined rules. Human expertise can be used in framing rules. The set of rules are stored in knowledge base. The rule base used for the fuzzy controller is given in Table 1. For example if speed deviation is NM and accelerating power is Z then output is NM. If speed deviation is PM and accelerating power is PM then output is PM, and so on.

- **Inference Mechanism:** Inference mechanism processes the input signals and generates output based on rules.
- **Defuzzification**: The output will be in the format of linguistic variable. In the final stage the linguistic variable are converted to crisp variable.

Table 1: Rule Base of Fuzzy Logic Controller

Speed Deviation	Accelerating Power						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	Z
NS	NB	NM	NM	NM	NS	NS	Z
Z	NM	NS	NS	Z	PS	PS	PM
PS	NS	Z	Z	PS	PS	PM	PM
PM	Z	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

Fuzzy Logic Power System Stabilizer

Normally speed deviation and acceleration are given as input to the controller. In the work presented in this paper speed deviation and accelerating power are given as input to the controller. The inputs are given to fuzzy logic controller through gain blocks K_1 and K_2. The output of FLC is voltage stabilizing signal which is fed to the synchronous machine for damping the oscillation in power system through gain K_3. Figure 4 show the FLPSS employed for the analysis.

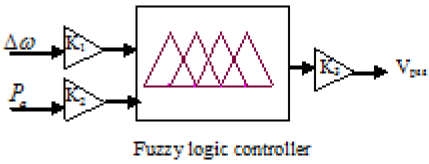

Figure 4: Basic Structure of Fuzzy Logic Power System Stabilizer

The gains K_1, K_2 and K_3 of the controller are tuned manually until the oscillations are damped at quicker rate. The gain values for three phase fault condition after tuning is K_1=6, K_2=0.097 and K_3=1.0.

FIS Editor

Using FIS editor the membership function for speed deviation and accelerating power is created. The rules are entered in the rule editor. The FLPSS created is included in the SIMULINK used to simulate the SMIB system. Figure 5 shows the membership function used for speed deviation.

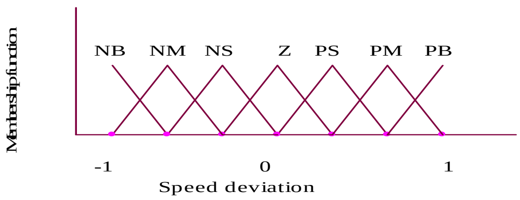

Figure 5: Membership Function for Speed Deviation

SYNTHESIS OF ACCELERATING POWER FOR STABILIZER

One of the inputs to FBPSS is the synthesized accelerating power (P_a). It can be obtained from speed deviation and electrical power as shown in Figure 6 [6].

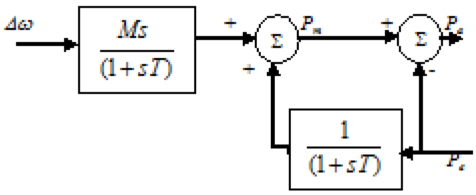

Figure 6: Synthesis of Accelerating Power Signal

M is the inertia constant of machine. To synthesis P_a, value of M=10 and T=0.02 secs is selected. When FLPSS is tuned to damp the oscillations the value of T obtained is 0.02 secs.

RESULTS AND DISCUSSIONS

The performance of the SMIB system is analyzed for the following two cases.

Five Percent Step Increase in V_{ref}

SMIB is analyzed for a five percent rise in V_{ref}. The step increase in V_{ref} occures at 1 sec. The results obtained from the system with fuzzy PSS and CPSS are illustrated.

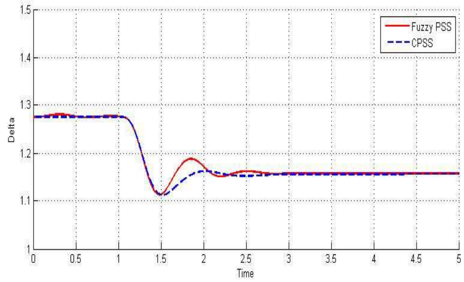

Figure 7: Plot of Delta with Conventional and Fuzzy PSS for Five Percent Rise in V_{ref}

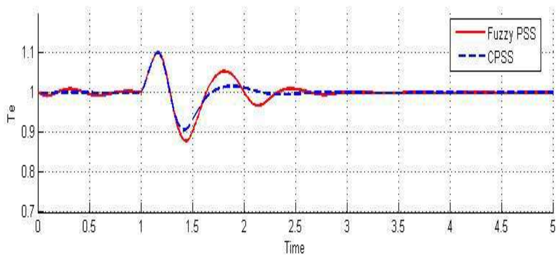

Figure 8: Plot of T_e with Conventional and Fuzzy PSS for Five Percent Rise in V_{ref}

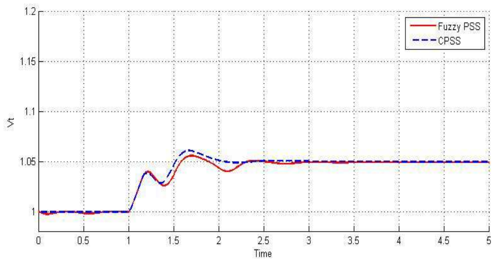

Figure 9: Plot of V_t with Conventional and Fuzzy PSS for Five Percent Rise in V_t

From the results we see that settling time for delta with FLPSS is 2.4 secs whereas with CPSS it is 3.0 secs. The settling time for T_e is 2.6 secs with FLPSS whereas with CPSS it is 3.1 secs. The settling time for delta and T_e is better

with FLPSS than CPSS. It is observed that the performance of FLPSS is better than CPSS

Three Phase Fault at Generator Terminal

SMIB is subjected to a three phase fault at the generator terminals. The three phase fault occures at 1 sec. The fault is cleared within five cycles. The results obtained from the system with CPSS and fuzzy PSS are tabulated.

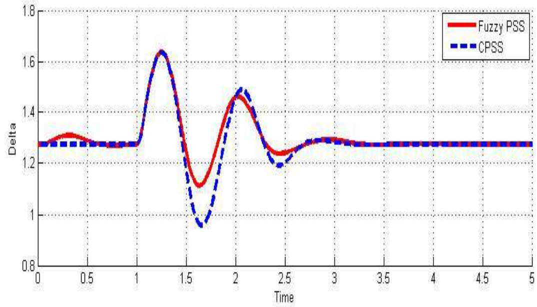

Figure 10: Plot of Delta with Conventional and Fuzzy PSS for Three Phase Fault

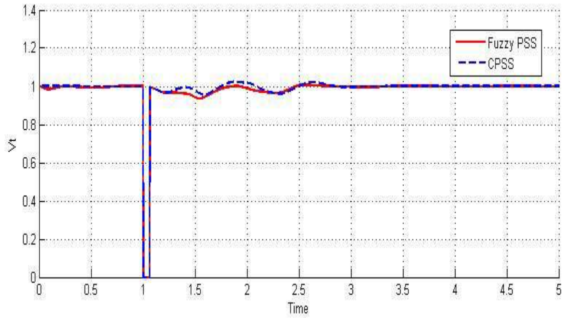

Figure 11: Plot of V_t With Conventional and Fuzzy PSS for Three Phase Fault

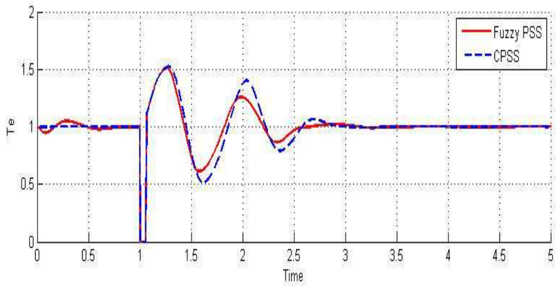

Figure 12: Plot of T_e with Conventional and Fuzzy PSS for Three Phase Fault

It is seen from the above results that the performance of fuzzy logic PSS is better than conventional PSS. The settling time for delta is lesser with fuzzy PSS. It settles down at 2.6 secs with FLPSS whereas with CPSS it takes 3.2 secs. Also with fuzzy PSS the over shoot for T_e is reduced with lesser settling time. The settling time for T_e with FLPSS is 2.6 secs whereas with CPSS it is 3.3 secs. Similarly the settling time for V_t with FLPSS is 2.5 secs whereas with CPSS it is 3.0 secs. The performance of FLPSS is good compared to CPSS.

CONCLUSIONS

In this paper the performance of fuzzy logic PSS with synthesized accelerating power input is highlighted. Accelerating power is synthesized using speed deviation and electrical power. FBPSS is created using SIMULINK.

The system is simulated using MATLAB and SIMULINK. The system is analyzed for two cases (a) five percent step increase in V_{ref}. (b) Three phase fault at the generator terminal. The impact of CPSS and FLPSS on the system is analyzed. The settling time for delta, V_t and P_e is lesser with FLPSS than with CPSS. It is observed that the performance of FLPSS is better than that of CPSS.

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APPENDICES

Appendix A

The machine data used for analysis are [6]:

The synchronous machine is connected to infinite bus through external reactance of x_e=0.4 pu, P_g=1.0, V_t=1.0, E_b=1.0

The machine data are: x_q=1.55, $x_d^{'}$=0.32, $T_{do}^{'}$=6.0, H=5, D=0, f_b=50 Hz, K_E=200, T_E=0.05, Fault occurs on generator terminal and the fault is cleared after 4 cycles. Limits on PSS output are +/- 0.05 pu and limit on E_{fd} =+/- 6.0 pu.

Appendix B

Abbreviations used in equations:

S_m =Slip speed of generator.

S_{mo} =Initial slip speed of generator.

δ= Rotor angle of the generator.

H= Inertia constant of generator.

$T_{do}^{'}$ =open circuit transient time constant.

T_m=Mechanical torque input to generator.

Te=Electrical torque output of generator.

D=Damping factor.

V_{fd} =Field voltage.

E'_q = q-axis component of the transient internal emf.

V_d =d-axis component of generator terminal voltage.

V_q = q-axis component of generator terminal voltage.

$x_d^{'}$ =d-axis transient reactance of generator.

x_d= d-axis steady state reactance.

$x_q^{'}$ =q-axis transient reactance of generator.

i_d =d-axis current.

V_{fd} = q-axis current.

V_{pss}= Power system stabilizer output.

K_a = Gain of power system stabilizer.